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## MAXIMUM RATES OF CONTROL MOTION OBTAINED FROM GROUND TESTS

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## SUMMARY

Ground tests were conducted in a specially constructed cockpit rig to determine the maximum rates of control-stick (elevator) motion and the corresponding maximum stick forces that could be exerted, as based on results obtained with a number of pilots.

The measurements indicate that the maximum rate of push on the control stick is greater than the maximum rate of pull; that the maximum rate of either push or pull is less when a mental restriction is imposed upon the pilot; and that the maximum rates at which the pilot thought he would apply elevator control forces in flight are considerably less than the rates at which he could apply these forces with the same stick stiffness.

## INTRODUCTION

The maximum rates of control motion as well as the maximum forces that a pilot can exert on the elevator controls must be taken into account in the formulation of rational design criterions for dynamic tail load computations. The maximum tail load consistent with the load factor in vertical-plane maneuvers results when an elevator motion is specified in which the elevator is moved as rapidly as possible to a maximum value and held there for such a time that, when the controls are abruptly reversed,

[redacted]

the maximum allowable positive load factor is just reached. Several investigations that have some bearing on this subject (references 1, 2, and 3) have already been completed, but they do not yield sufficient data on the rate of control motion. In references 1 and 2 the emphasis is placed on the quickness with which a maximum force can be developed, whereas in reference 3 tests of the maximum steady forces applied by a pilot in various positions was reported.

The question of how the pilot actually moves the controls depends on such unpredictable variables as the physiological and psychological makeup of the pilot, which are in turn influenced by the "feel" of the airplane. This subject is largely outside the scope of the present paper, which presents mainly the results of tests made expressly to determine the effect of several variables on the maximum possible rates of stick motion. Nine pilots, varying in physical fitness and in flying experience, participated in the performance of these tests.

## APPARATUS

The rig used in the tests (see fig. 1) consisted of an adjustable bucket-type pilot's seat, a control stick, and a rudder bar that were mounted on a heavy wooden table. The relative positions of the seat, stick, and rudder bar were similar to those used in present-day fighter airplanes. A resisting force was applied to the stick by means of two preloaded spiral springs, which were attached at one end to a movable shelf that was installed under the table top. The other ends of the springs were attached to a collar, which could slide on a projection of the stick that extended below the table top. Adjusting the height of the shelf and of the collar permitted different spring restraints to be imposed on the stick.

It was realized at the outset that general relationships that would hold for all cases could not be established between the force and the stick deflection. With the type of control motion contemplated, an adjustment of the springs such that an additional restraint would be imposed during the return motion appeared necessary. This adjustment would be in accordance with conditions that would occur in flight when an angular velocity was present and a convergent elevator was used. For this purpose, an adjustable nonreturn mechanism was attached to the spring supplying the restraint in the pull direction. The action of this apparatus is illustrated in figure 2, which shows the time variation obtained for the stick position and the stick force with the mechanism in operation. A diagrammatic view of the stick system is also shown on this figure. A strict interpretation of the results of figure 2 in terms of the corresponding aerodynamic parameters of the substitute elevator is not possible because varying values of the parameters would be obtained for different parts of the curve.

The position of the stick was recorded by a control-position recorder mounted on top of the table. A timer, also mounted on top of the table, was used to impress timing signals on the control-position record in order that accurate time histories could be obtained. The relation between the stick position and the stick force was obtained by separate calibrations for which the stick was pulled back slowly by a spring scale with the shelf in each of the positions used during the tests.

A thigh belt was used to secure the pilot in the seat. Although the belt restricted the reach of the pilot, the results obtained by its use were believed to be more consistent than would be obtained if no belt were used.

## METHOD AND TESTS

Three types of stick motion were investigated. For each type, resisting forces of 33.3, 16.6, 8.3, and 4.2 pounds per inch of control-stick displacement were imposed on the control stick. For the first part of the investigation, measurements were made of the maximum rate and corresponding maximum force obtained when the stick was pulled and then pushed as rapidly as possible with no limitation as to either displacement or force. In addition, one pilot was instructed to move the control stick in this same manner with no resisting force other than inertia on the stick.

For the second part of the investigation, the pilot was requested to use only one-half the displacement obtained in the first part. This condition was thought to simulate more nearly the flight condition inasmuch as the pilot would generally be constrained as to amount of deflection by the knowledge that in flight he might obtain larger accelerations than he could comfortably stand.

For the third part of the investigation, measurements were made of the maximum rate and corresponding maximum forces at which the subject pilot thought he would move the control stick to pull out from a diving attitude if forces similar to those applied to the cockpit rig were experienced in the dive. These measurements are limited in that they depended on the extent of flying experience and imagination of each of the subject pilots.

The maximum rates for the tests of the three types of stick motion were obtained directly from the record films by measuring the maximum slopes thereon and the rate of film travel at the midpoint of the maximum slope. Maximum forces also were obtained from the film records by reading the maximum deflections of the stick.

## ACCURACY

The measurements of the control-stick rates are believed to be accurate to ±10 inches per second, whereas the measurements for maximum stick forces are accurate to ±3 pounds. These values are largely based upon the accuracy to which the film records can be read.

## RESULTS AND DISCUSSION

The results of the measurements made to determine the maximum rates at which a pilot can move the control stick with various restraints in the control system are presented in figures 3 to 12. These figures show that considerable scatter exists in the data. When this scatter was first noted, consideration was given to plotting the maximum rate of stick movement for each pilot against the power exerted at the time of maximum rate in order to reduce the scatter. The scatter, however, still persisted and it was finally decided to plot the maximum rates against either the maximum force or the maximum stick displacement for a given run without distinguishing between pilots.

All the results given in figures 3 to 6 have one thing in common; that is, with an increase in the maximum stick force there is a definite decrease in the maximum rate of stick motion. This result contradicts results of previous tests (reference 1), which report that forces have little or no effect on the rate of control movements provided they are within the pilot's capability.

Figures 7 to 10 show that the maximum rate also increases with stick displacement. This variation is to be expected from the results in figures 3 to 6, however, because with the system used the force is proportional to the displacement.

Comparison of the results shown in figure 11 and 12, which represent the measurements made to determine the maximum rates of stick motion during simulated dive pull-outs, with results shown in figures 9 and 10 shows that the maximum rates at which the pilots think they would move the stick is considerably lower than the rate at which they could move the stick. All the pilots were of the opinion that the highest value of restraint used in the tests was more than would be experienced with present-day airplanes; however, records of such forces obtained in flight on fighter-bomber airplanes indicate that restraints of this magnitude may exist.

A summary of the rates of stick motion given in table I shows that the rate of motion is from 25 to 60 percent greater in the push direction than in the pull direction. Factors that contribute to this difference are: (1) the returning force introduced by the system used effected the first part of the pushing motion, (2) the distance the stick may be moved is greater in the push direction, and (3) the pilot is in a more favorable position for performing the pushing operation.

From the summary given in table I it may also be seen that the maximum rates obtained in either direction of motion with no restriction were from 20 to 50 percent greater than those obtained with a restriction as to the amount of travel. This difference in the rate seems a reasonable one in view of the restrictions imposed. It also seems reasonable that different results would be obtained if a different restriction had been imposed on the pilot.

## CONCLUSIONS

Tests conducted by means of a specially constructed cockpit rig to determine maximum rates of control-stick motion indicate the following conclusions:

1. The maximum rates of stick movement are greater in the push direction than in pull whether there is a mental restriction or no restriction imposed on the pilot as to stick travel.

2. The maximum rates of stick movement increase both with a decrease in maximum stick force and with an increase in maximum stick displacement.

3. The maximum rate at which a pilot believed that he would move the control stick is considerably lower than the rate at which he could move the stick.

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## REFERENCES

1. Superintendent, Royal Aircraft Factory: Experiments on the Possible Rate at Which a Pilot Can Pull Back the Control Column in an Aeroplane. R. & M. No. 282, British A.C.A., 1916.

2. Hertel, Heinrich: Determination of the Maximum Control Forces and Attainable Quickness in the Operation of Airplane Controls. NACA TM No. 583, 1930.

3. Gough, M. N., and Beard, A. P.: Limitations of the Pilot in Applying Forces to Airplane Controls. NACA TN No. 550, 1936.

TABLE I

RATES OF STICK MOTION MEASURED IN GROUND TESTS

| Stick force per unit displacement (lb/in.) | Maximum rates of stick motion (in./sec) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No restrictions | | | | With mental restrictions | | | |
| | Pull | | Push | | Pull | | Push | |
| | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 0 | 75 | 140 | 105 | 251 | -------- | ------- | ------- | --------- |
| 4.2 | 47 | 110 | 80 | 140 | 35 | 99 | 66 | 114 |
| 8.3 | 49 | 103 | 65 | 124 | 31 | 68 | 55 | 100 |
| 16.6 | 33 | 80 | 47 | 107 | 22 | 47 | 37 | 80 |
| 33.3 | 23 | 53 | 33 | 63 | 18 | 33 | 25 | 40 |

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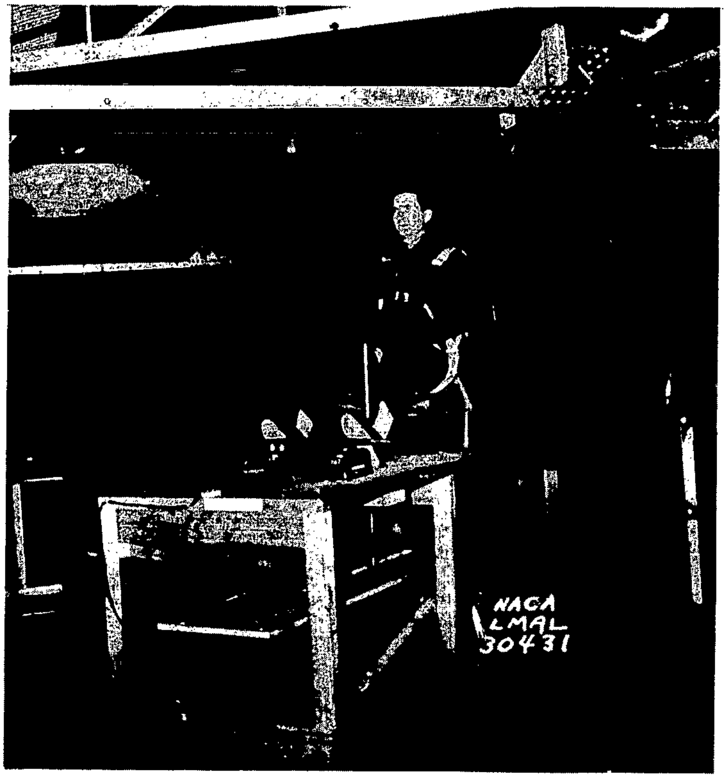
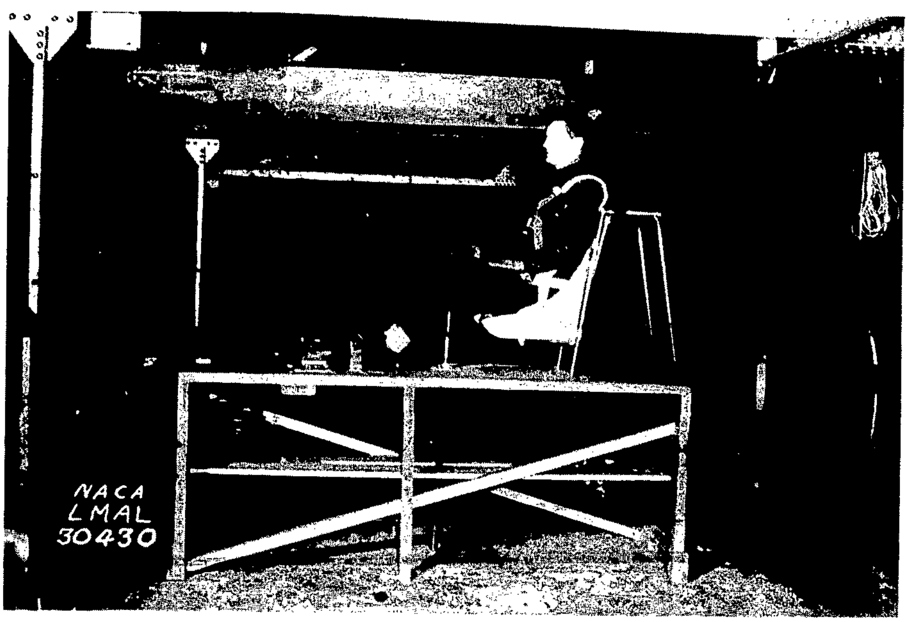
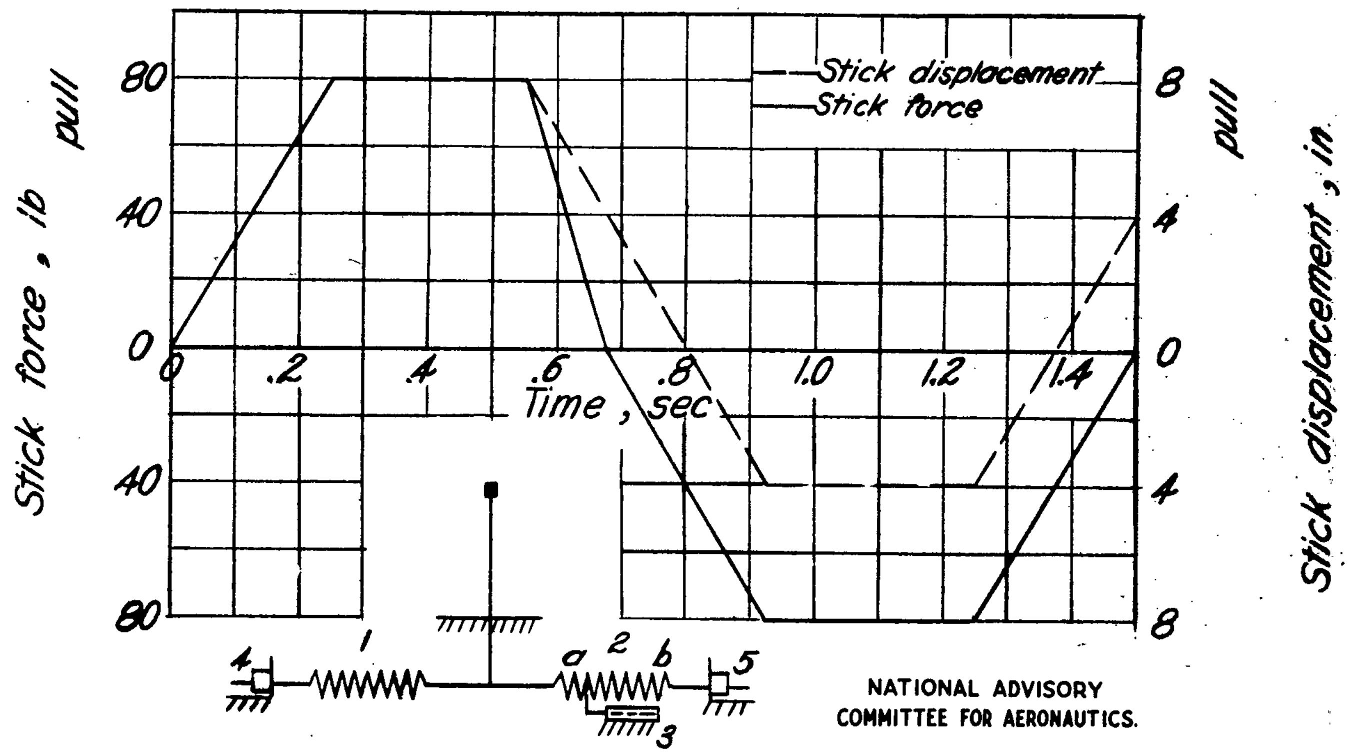



(a) Three-quarter front view.




(b) Side view.

Figure 1.- Cockpit rig used to obtain maximum rates of control motion.




1-Push-resisting tension spring
2-Pull-resisting tension spring
3-Mechanism allowing part b of 2 to move toward left only. (Positioned after adjustment of 5)
4,5-Means for adjusting pre-tension of 1,2

Figure 2.- Typical time history of stick force and displacement when adjustable nonreturn mechanism on cockpit rig is used.

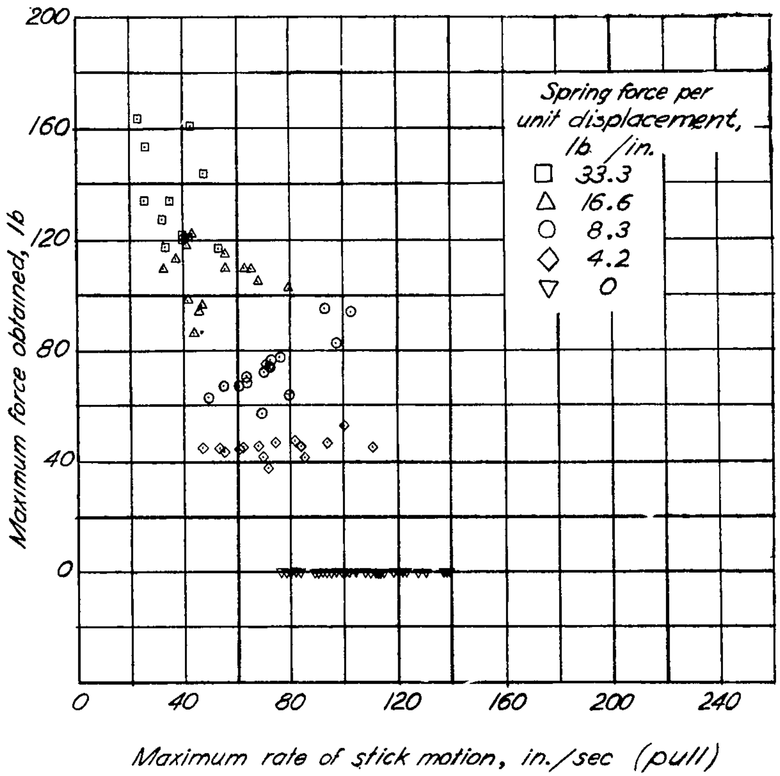



Figure 3.- Variation of maximum rate of stick motion with maximum force obtained in ground tests. No restrictions; pull force exerted.

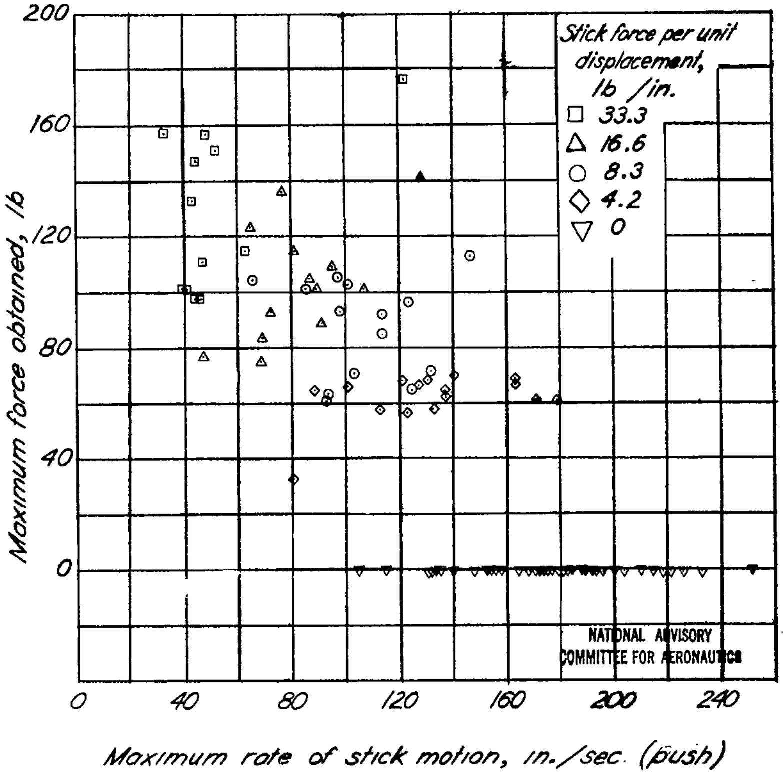



Figure 4.- Variation of maximum rate of stick motion with maximum force obtained in ground tests. No restrictions; push force exerted.

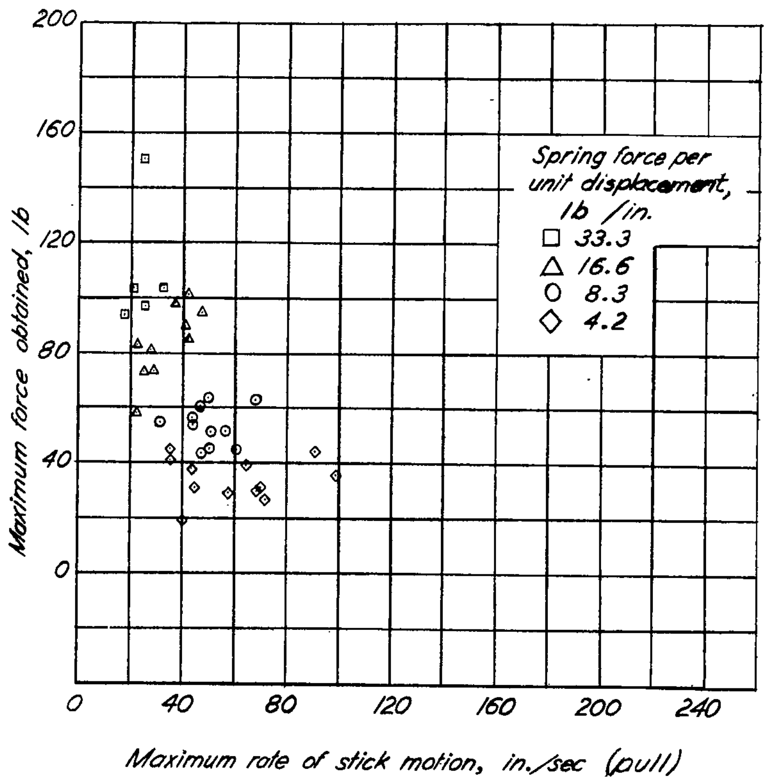



Figure 5.- Variation of maximum rate of stick motion with maximum force obtained in ground tests. With mental restriction; pull force exerted.

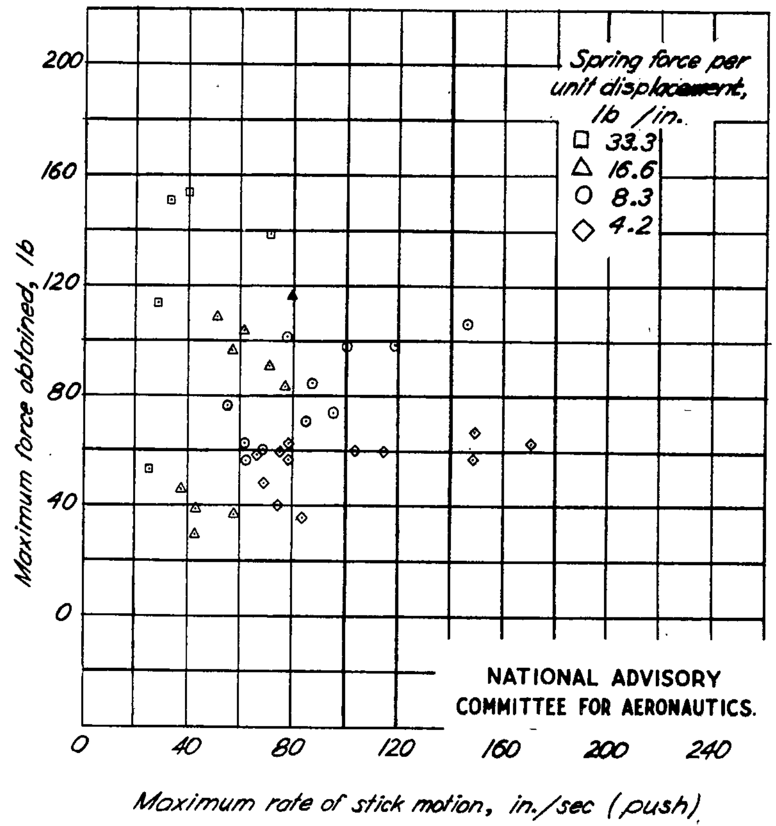



Figure 6.-Variation of maximum rate of stick motion with maximum force obtained in ground tests With mental restriction; push force exerted.

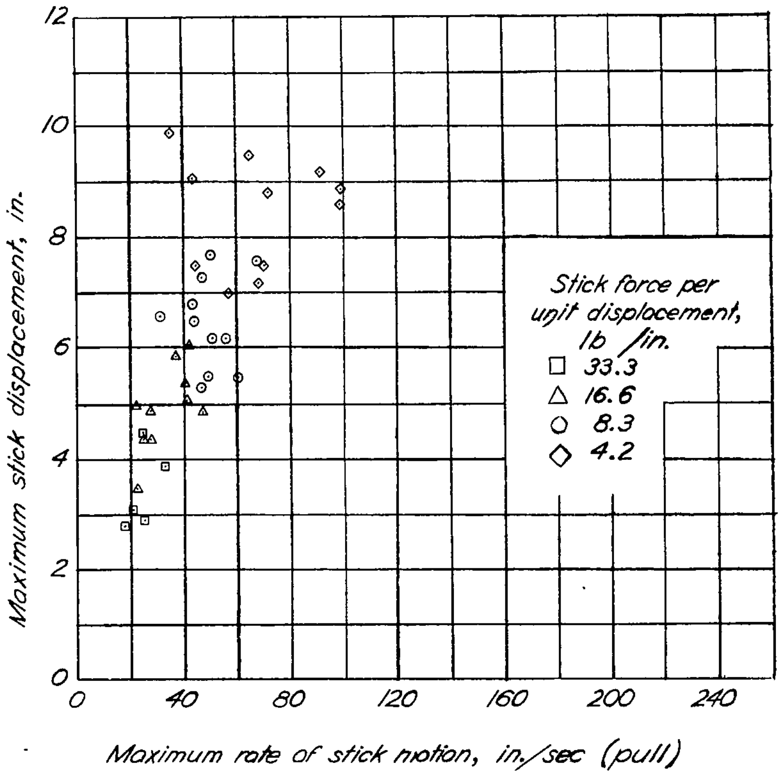



Figure 7.- Variation of maximum rate of stick motion with maximum displacement obtained in ground tests. No restrictions; pull force exerted.

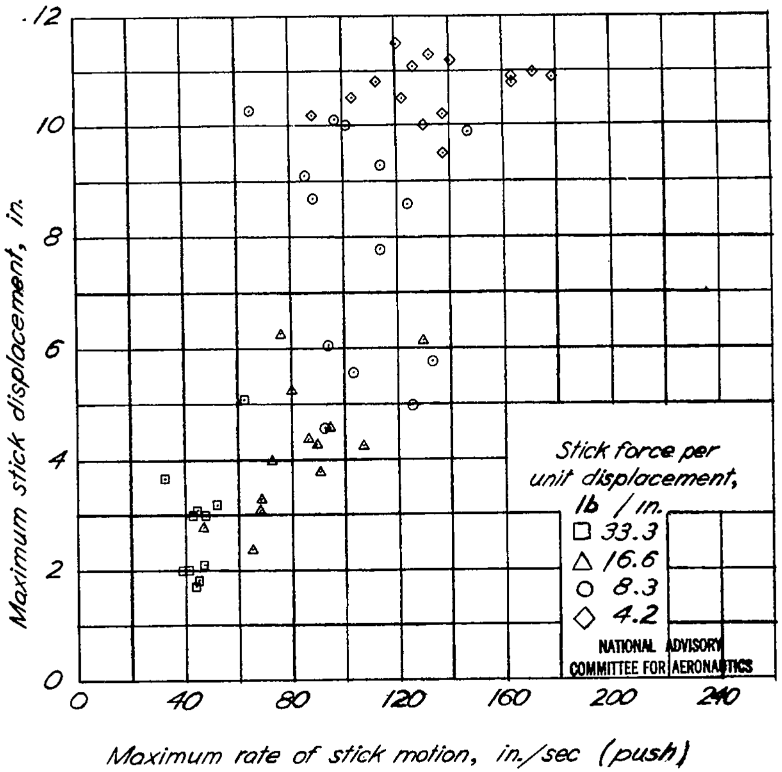



Figure 8.- Variation of maximum rate of stick motion with maximum displacement obtained in ground tests. No restrictions; push force exerted

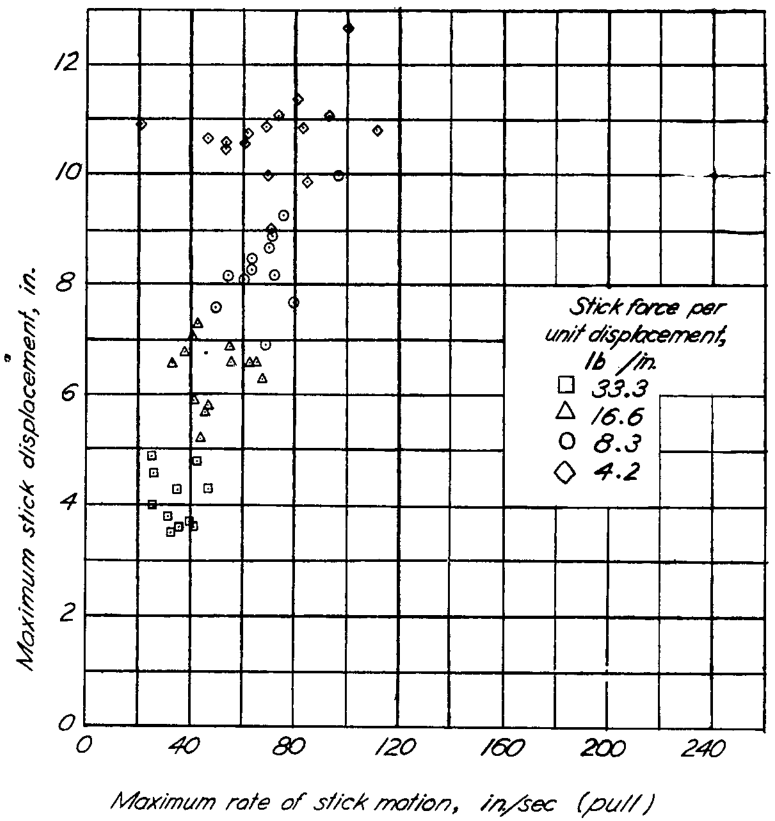



Figure 9.- Variation of maximum rate of stick motion with maximum displacement obtained in ground tests With mental restriction; pull force exerted.

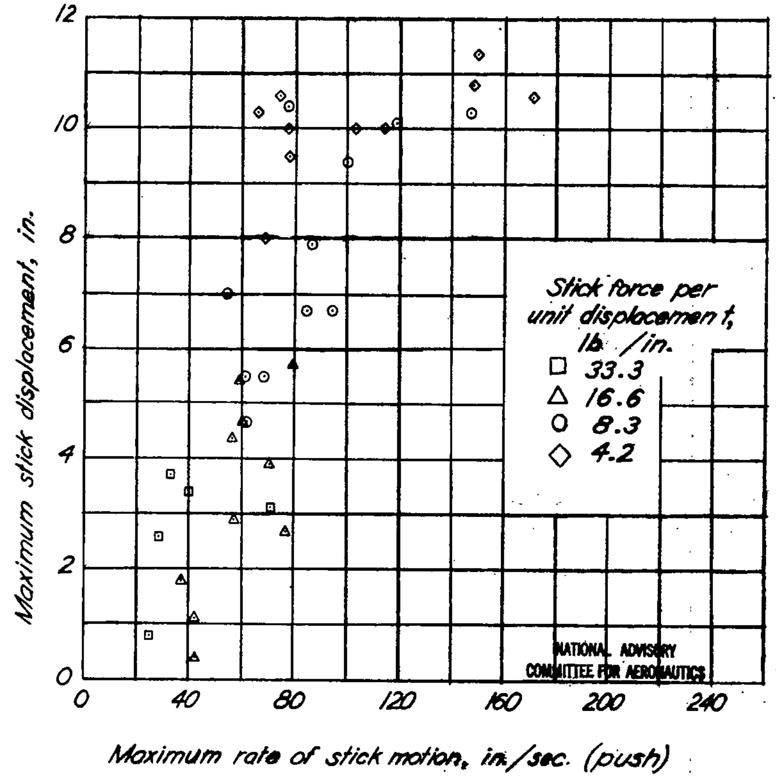



Figure 10-Variation of maximum rate of stick motion with maximum displacement obtained in ground tests. With mental restriction; push force exerted.

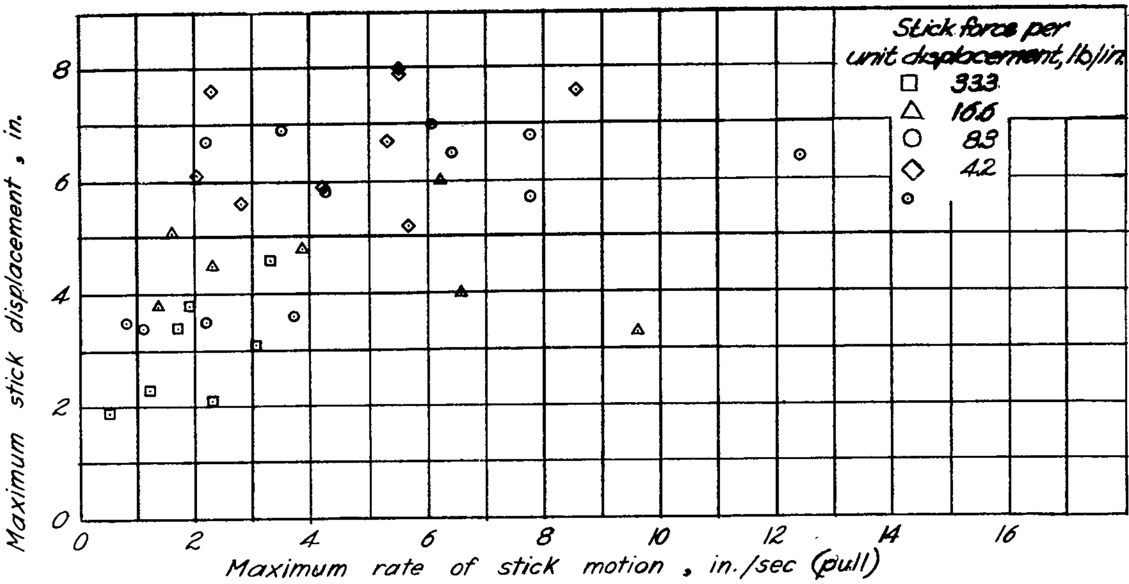



Figure 11. - Variation of maximum rate of stick motion with maximum stick displacement obtained in ground tests during a simulated pull-out; pull force exerted.

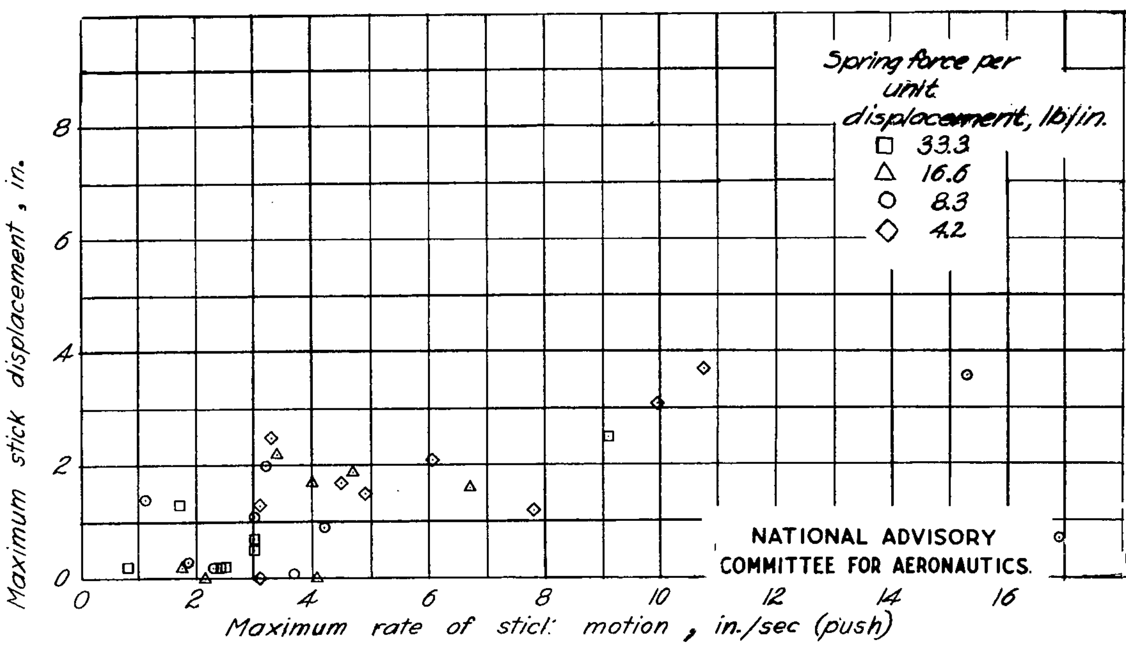



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Figure 12. - Variation of maximum rate of stick motion with maximum stick displacement obtained in ground tests during a simulated pull-out; push force exerted.